# Novel, Efficient, Low Cost Technology for Direct Air Capture of $CO_2$ and its Removal from Low Concentration Streams

## primary project goal

During the Phase I project, Emissol LLC designed, modeled, prototyped, and tested a novel honeycomb contactor smaller than typical honeycomb contactors. The contactor was rigorously tested both experimentally and in mathematical models. Good agreement was observed between the project's test data and math-modeling results. It was observed that the novel contactor captures and removes carbon dioxide ($CO_2$) at a high rate while also requiring approximately 40% less sorbent than typical honeycomb contactors. This was a significant finding, as for many DAC systems the sorbent cost could be 80–85% of the total capture cost.[1] Given the cost-reduction capability of the novel contactor, the total direct air capture (DAC) cost could be reduced by approximately 30%.

During Phase II, Emissol plans to optimize their novel contactor for an even higher capture rate, as well as for greater DAC cost savings. The project team is working closely with a national lab on prototyping, testing, and manufacturing the contactor.

## technical goals

- Reduce contactor thermal mass in order to minimize thermal energy and lower its associated costs (operating expenses [OPEX]).
- Study sorbent loading in mesopores of the contactor for enhanced, internal mass diffusion, further increasing $CO_2$ transport rate.
- Optimize the geometry of the contactor at unit level (e.g., to minimize pressure drop) and at system level (e.g., to meet the capture target at lowest cost).
- Develop a low-cost, scalable, cost-competitive manufacturing method to produce the novel honeycomb.
- Perform a techno-economic analysis (TEA) to assess the impact of the resulting contactor on reducing the total DAC cost.
- Develop a process model for parametric studies and data feeding into the TEA.

## technical content

Honeycomb monolith substrates have found successful use in DAC. A noteworthy example is that by Global Thermostat (Figure 1), where such contactors coated with amine compounds adsorb $CO_2$, then desorb and release $CO_2$ every 15 minutes

**program area:**
Carbon Dioxide Removal

**ending scale:**
Laboratory Scale

**application:**
Direct Air Capture

**key technology:**
Sorbents

**project focus:**
Monolith Amine-Based Sorbent for $CO_2$ Capture

**participant:**
Emissol LLC

**project number:**
SC0020860

**predecessor projects:**
N/A

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**start date:**
06.29.2020

**percent complete:**
57%

[1] National Academy of Science, Engineering and Medicine. "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda." National Academies Press. (2019).

at near-perfect purity of 98–99%. Another example is Carbon Engineering Ltd., where a solvent could capture 1 million tonnes (Mt) of $CO_2$/year, used next to produce various products, such as synthetic fuels. The primary reason for Global Thermostat and Carbon Engineering using honeycomb-type contactors is that they provide plenty of surface area ideal for $CO_2$ adsorption/desorption while yielding very low pressure drop and, hence, low pumping power energy cost for air flow to pass through contactors.

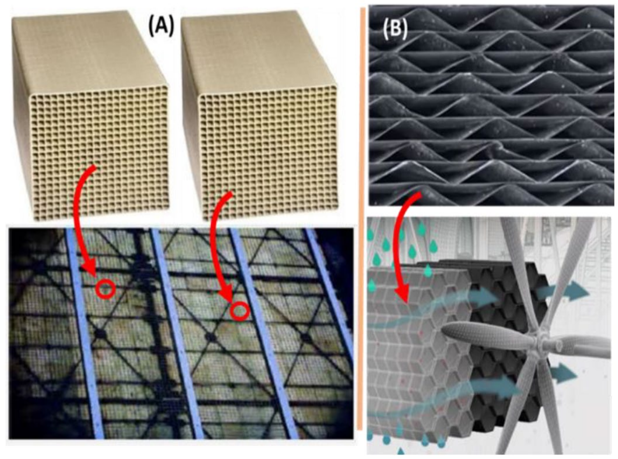


**Figure 1: (A) Top: Ceramic honeycomb (monolithic) contactors used by Global Thermostat. Bottom: Their large stack at the Global Thermostat plant. (B) Top: Carbon Engineering's array of contactors, honeycomb-like structures (one section shown only) for air flow (bottom) and $CO_2$ removal using a solvent.**

However, such honeycombs have one major limitation: in their straight channels, $CO_2$ species travel to the sorbent-coated wall (or to the solvent) via diffusion, an inherently slow process (i.e., the channel's base flow, the convection, has no role in $CO_2$ transport to the sorbent). Removing this major barrier, Emissol has invented a proprietary honeycomb contactor replacing the slow $CO_2$ diffusion with the much faster convective transport, hence dramatically increasing the rate of $CO_2$ transport to the sorbent (wall). Further, since the channel mass transfer increases faster than its friction force does, it yields a "net gain" in performance versus its pressure drop increase. The contactor makes available faster $CO_2$ adsorption/desorption rates (i.e., grams/seconds) and thus higher capture frequency. Therefore, the potential exists to replace mainstream contactors, some discussed above, with this project's transformational contactor, markedly reducing DAC cost. A block flow diagram of the overall DAC process is shown in Figure 2.

Particularly, Phase I results indicate that, given its markedly faster capture rate, the Emissol contactor can also be downsized by approximately 40% (relative to a typical, baseline contactors) without impacting the captured $CO_2$ target (tonnes/unit time), in turn enabling a major sorbent reduction by about the same ratio (40%). Since the adsorbent capital expenditure (CAPEX) forms more than 80% of the total DAC cost,[1] the savings yields a DAC cost reduction by approximately 30%—a marked reduction in the total DAC cost.

Phase II research and development (R&D) focuses on key tasks to further enhance the contactor impact on the total DAC cost reduction (i.e., above and beyond cost-saving gains achieved in Phase I).

**Task 1**. Reduce contactor thermal mass, to reduce thermal energy for desorption and its associated costs.

**Task 2**. Sorbent loading in mesopores of the contactor: sorbent-contactor optimization.

**Task 3**. Optimizing the contactor geometry, first at the honeycomb scale (local unit), and next at the system scale. Both efforts target maximizing cost savings for DAC.

**Task 4**. Developing a low-cost, scalable, manufacturing method.

**Task 5**. Develop a TEA.

***Proposed Module Design*** – Honeycomb contactor with switching between adsorption and desorption modes.

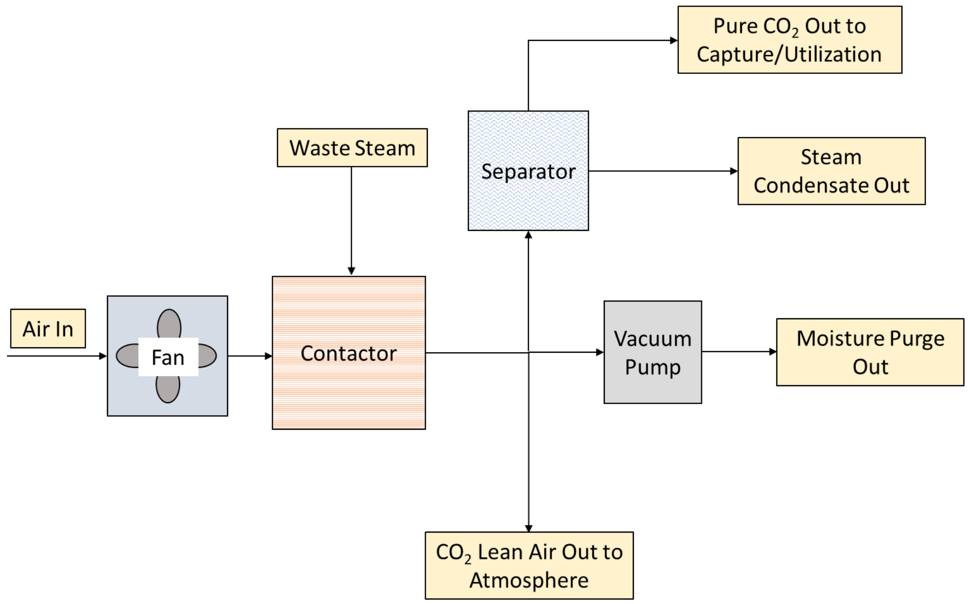


**Figure 2: Block flow diagram of DAC system.**

### Definitions:

***Cost of Carbon Captured*** – Projected cost of capture per mass of $CO_2$ captured under expected operating conditions.

***Capital Expenditures*** – Projected capital expenditures in dollars per tonne of $CO_2$ captured.

***Operating Expenditures*** – Projected operating expenditures in dollars per tonne of $CO_2$ captured.

***Calculations Basis*** – The TEA calculation is based on the study referenced earlier via footnote.[1]

***Scale of Validation of Technology Used in TEA*** – The TEA is based on contactor-scale modeling results. The model shows good agreement with the experiment.

## technology advantages

- Novel contactor design.
- Reduced contactor size to roughly half the size of conventional honeycomb contactors.
- Reduced sorbent use (by approximately half).
- Enables faster capture cycles, hence accelerated capture/release cycle, and increases the net capture amount (tonne $CO_2$/day).
- Lowers thermal energy required for sorbent regeneration and low pressure drop.

## R&D challenges

- Engineering-enhanced pore diffusion of $CO_2$ in the solid sorbent; managing the intricacy between support's pore size and powder (sorbent) pore size in a manufacturing process aiming at faster pore diffusion.
- Optimizing the contactor geometry at the honeycomb scale and at the system level.

## status

Emissol has developed its own coating process for applying the sorbent to the structured support. The sorbent has been identified; honeycomb prototyping and model development and enhancements are currently under way.

## available reports/technical papers/presentations

Masoudi, M. "Novel, Efficient, Low Cost Technology for Direct Air Capture of $CO_2$ and its Removal from Low Concentration Streams." NETL Direct Air Capture Kickoff Meeting. February 2021. *https://netl.doe.gov/sites/default/files/netl-file/21DAC_Masoudi.pdf*.